

## REPORT DOCUMENTATION PAGE

|                                                                                                                                                                                                                                                                                                                                          |       |                                                |                                                                                                                   |                                                         |                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------|
| 1a. REPORT SECURITY CLASSIFICATION<br>unclassified                                                                                                                                                                                                                                                                                       |       |                                                | 1b. RESTRICTIVE MARKINGS                                                                                          |                                                         |                           |
| 2. SECURITY CLASSIFICATION AUTHORITY                                                                                                                                                                                                                                                                                                     |       |                                                | 3. DISTRIBUTION/AVAILABILITY OF REPORT<br>approved for public release; distribution unlimited                     |                                                         |                           |
| AD-A221 240                                                                                                                                                                                                                                                                                                                              |       |                                                | 5. MONITORING ORGANIZATION REPORT NUMBER(S)                                                                       |                                                         |                           |
| 6a. NAME OF PERFORMING ORGANIZATION<br>UNC Chemistry Department                                                                                                                                                                                                                                                                          |       | 6b. OFFICE SYMBOL<br>(If applicable)           | 7a. NAME OF MONITORING ORGANIZATION<br>Office of Naval Research (Code N00014)                                     |                                                         |                           |
| 6c. ADDRESS (City, State, and ZIP Code)<br>CB #3290, Venable Hall<br>The University of North Carolina<br>Chapel Hill, NC 27599-3290                                                                                                                                                                                                      |       |                                                | 7b. ADDRESS (City, State, and ZIP Code)<br>Chemistry Program<br>800 N. Quincy Street<br>Arlington, Virginia 22217 |                                                         |                           |
| 8a. NAME OF FUNDING SPONSORING ORGANIZATION<br>Office of Naval Research                                                                                                                                                                                                                                                                  |       | 8b. OFFICE SYMBOL<br>(If applicable)           | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>Contract #N00014-86-K-0305                                     |                                                         |                           |
| 8c. ADDRESS (City, State, and ZIP Code)<br>Chemistry Program<br>800 N. Quincy Street, Arlington, VA 22217                                                                                                                                                                                                                                |       |                                                | 10. SOURCE OF FUNDING NUMBERS                                                                                     |                                                         |                           |
|                                                                                                                                                                                                                                                                                                                                          |       |                                                | PROGRAM<br>ELEMENT NO                                                                                             | PROJECT<br>NO                                           | TASK<br>NO                |
|                                                                                                                                                                                                                                                                                                                                          |       |                                                |                                                                                                                   |                                                         | WORK UNIT<br>ACCESSION NO |
| 11. TITLE (Include Security Classification)<br>SILICON OXIDATION STUDIES: ORIGINS OF THE PROPERTIES OF THERMALLY PREPARED SiO <sub>2</sub> FILMS                                                                                                                                                                                         |       |                                                |                                                                                                                   |                                                         |                           |
| 12. PERSONAL AUTHOR(S)<br>Dr. Eugene A. Irene                                                                                                                                                                                                                                                                                            |       |                                                |                                                                                                                   |                                                         |                           |
| 13a. TYPE OF REPORT<br>Final                                                                                                                                                                                                                                                                                                             |       | 13b. TIME COVERED<br>FROM May 1986 TO May 1988 |                                                                                                                   | 14. DATE OF REPORT (Year, Month, Day)<br>April 25, 1990 |                           |
| 15. PAGE COUNT                                                                                                                                                                                                                                                                                                                           |       |                                                |                                                                                                                   |                                                         |                           |
| 16. SUPPLEMENTARY NOTATION                                                                                                                                                                                                                                                                                                               |       |                                                |                                                                                                                   |                                                         |                           |
| 17. COSATI CODES                                                                                                                                                                                                                                                                                                                         |       |                                                | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)                                 |                                                         |                           |
| FIELD                                                                                                                                                                                                                                                                                                                                    | GROUP | SUB-GROUP                                      |                                                                                                                   |                                                         |                           |
|                                                                                                                                                                                                                                                                                                                                          |       |                                                |                                                                                                                   |                                                         |                           |
|                                                                                                                                                                                                                                                                                                                                          |       |                                                |                                                                                                                   |                                                         |                           |
| 19. ABSTRACT (Continue on reverse if necessary and identify by block number)<br><br>This research comprises a study of the origins of mechanical, optical and electronic properties of thermally grown thin SiO <sub>2</sub> films on Si substrates as related to the film growth mechanisms and of the cleaning of Si and InP surfaces. |       |                                                |                                                                                                                   |                                                         |                           |
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT<br><input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS                                                                                                                                                         |       |                                                | 21. ABSTRACT SECURITY CLASSIFICATION<br>unclassified                                                              |                                                         |                           |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>Dr. David L. Nelson                                                                                                                                                                                                                                                                               |       |                                                | 22b. TELEPHONE (Include Area Code)<br>(202) 696-4410                                                              |                                                         | 22c. OFFICE SYMBOL        |

## Accomplishments During Contract

Under ONR sponsorship, we have discovered that the initial Si oxidation kinetics is dependent on the orientation of the Si substrate and the number density of Si atoms. Also there is a change in order for thicker films, i.e., a crossover effect. We have discovered an ordering of decreasing intrinsic film stress and decreasing SiO<sub>2</sub> film density, with increasing oxidation temperature for post crossover SiO<sub>2</sub> films. Furthermore, the literature reports other parallel trends in the electronic behavior of the Si-SiO<sub>2</sub> interface (fixed charge,  $Q_f$ , and interface trapped charge,  $Q_{it}$  with oxidation temperature. Many of the oxidation kinetics and electronics effects have been vaguely ascribed to pre-oxidation Si surface treatments. The scientific strategy for the research effort was to elucidate the apparent interrelationships between the observed oxidation kinetics effects and the SiO<sub>2</sub> physical and interfacial electronic properties. In addition to the above discoveries which were partly based on previous ONR support of our research, several entirely new and both scientifically and technologically important discoveries were made in the contract period:

1. Correlation of film stress with density and Youngs modulus as measured using both a laser beam reflection technique in the present research and IR techniques in collaboration with Lucovsky's group at NC State university (also funded by ONR). The agreement and consistency of the two techniques lends considerable credence to our previous stress measurements.

2. In-situ ellipsometric measurement of both HF and NH<sub>4</sub>OH effects on the Si surface. A bare Si surface is found after NH<sub>4</sub>OH treatment in contrast with a film on Si after HF treatment. These differences may now help to explain the longtime mystery of different Si surface properties after these accepted cleaning steps and with the development of the in-situ techniques for this kind of research the details of the liquid phase cleaning process on Si is elucidated in detail.

3. In-situ ellipsometric measurements of cleaning of InP surfaces. Different optical properties for the InP surface have been measured as a result of different literature cleaning procedures. Procedures that yield reproducible optical properties have been identified. These results pave the way for further passivation studies on the InP surface.

## Technical Reports

ONR Report #

Report Title

- 11                    The Influence of Silicon Surface Cleaning Procedures on Silicon Oxidation
- 12                    The Effect of Surface Orientation on Silicon Oxidation Kinetics
- 13                    Redistribution of Arsenic in Silicon during High Pressure Thermal Oxidation
- 14                    Thermionic Emission Model for the Initial Regime of Silicon Oxidation
- 15                    Thermal Oxidation of Silicon: New Experimental Results & Models
- 16                    Models for the Oxidation of Silicon
- 17                    An In-Situ Study of Aqueous HF Treatment of Silicon by Contact Angle Measurement and Ellipsometry
- 18                    SiO<sub>2</sub> Film Stress Distribution during Thermal Oxidation of Si
- 19                    Thermal Oxide Growth on Silicon: Intrinsic Stress & Silicon Cleaning Effects
- 20                    Silicon Oxidation Studies: A Review of Recent Studies on Thin Film Silicon Dioxide Formation
- 21                    An-situ Ellipsometric Study of Aqueous NH<sub>4</sub>OH Treatment of Silicon

### Journal Articles

E.A. Irene, "New Results on Low Temperature Oxidation of Silicon," *Phil. Mag.* B,55, 131 (1987).

E. Kobeda and E.A. Irene, "Intrinsic SiO<sub>2</sub> Film Stress Measurements on Thermally Oxidized Si," *J. Vac. Sci. Technol. B.* 5, 15 (1987).

N.M. Ravindra, J. Narayan, D. Fathy, J.K. Srivastava and E.A. Irene, "Silicon Oxidation and Si-SiO<sub>2</sub> Interface of Thin Oxides," *J. Mat. Research*, Vol. 6 Nov./Dec. (1986).

G. Gould and E.A. Irene, "The Influence of Silicon Surface Cleaning Procedures on Silicon Oxidation," *J. Electrochem. Soc.*, 134, 1031 (1987).

S.S. Choi, M.Z. Numan, E.A. Irene and W.K. Chu, "Anomaly of Temperature Dependent Oxidation Rate during Low Temperature Oxidation of Heavily Doped Silicon," J. Appl. Phys. (1987).

G. Lucovsky, M.J. Mantini, J.K. Srivastava and E.A. Irene, "Low Temperature Growth of Silicon Dioxide Films: A Study of Chemical Bonding by Ellipsometry and Infrared Spectroscopy," J. Vac. Sci. Technol. B. 5, 530 (1987).

E.A. Irene, "Thermal Oxidation of Silicon: New Experimental Results and Models," Appl. Surface Sci., 30, 1 (1987).

E.A. Irene, "Models for the Oxidation of Si," CRC Critical Reviews in Solid State and Materials science, Ed. J.E. Greene, Vol. 14 (2), pg. 175-223 (1988).

E.A. Lewis and E.A. Irene, "The Effect of Surface Orientation on Silicon Oxidation Kinetics," J. Electrochem. Soc., 134, 2332 (1987).

E.A. Irene and E.A. Lewis, "Thermionic Emission Model for the Initial Stage of Silicon Oxidation," Appl. Phys. Lett., 51, 767 (1987).

G. Gould and E.A. Irene, "An In-Situ Study of Aqueous HF Treatment of Si by Contact Angle Measurement and Ellipsometry," J. Electrochem. Soc., 135, 1535 (1988).

E. Kobeda and E.A. Irene, "SiO<sub>2</sub> Film Stress Distribution during Thermal Oxidation of Si," Journal of Vacuum Science Technology B, 6, 574 (1988).

Post-Docs

Dr. Jitendra Srivastava  
Dr. Uean-Sin Pahk

Total PhD Students on Research

E. Kobeda  
G. Gould  
S.C. Vitkavage  
X. Liu  
S. Chongsawangvirod  
P. Delalio (MS)

Students Finishing Ph.D.

E. Kobeda  
G. Gould



|                    |                                     |
|--------------------|-------------------------------------|
| Accession For      |                                     |
| NTIS GRA&I         | <input checked="" type="checkbox"/> |
| DTIC TAB           | <input type="checkbox"/>            |
| Unannounced        | <input type="checkbox"/>            |
| Justification      |                                     |
| By                 |                                     |
| Distribution/      |                                     |
| Availability Codes |                                     |
| Dist               | Avail and/or Special                |
| A-1                |                                     |